

LETTERS TO THE EDITOR.

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Density and Figure of Close Binary Stars.

WHEN one star revolves round another in an orbit of which the plane is coincident, or nearly so, with the line of sight, an eclipse of one star by the other will take place every revolution. We have, in such circumstances, the well-known phenomenon of Algol variation.

It is evident that the duration, extent, and nature of the eclipse will depend upon the size and brightness of the component stars, and on the magnitude, inclination, and eccentricity of the orbit in which they move.

In practice, of course, the problem is the indirect one of determining the elements of orbital movement of the system from the observed variation in the star's brightness. That is to say, having ascertained, either photometrically or photographically, the manner in which the light of the star varies, we determine the physical conditions which have produced this variation.

There is no field of astronomical research in the present day so interesting, or so rich in future possibilities, as that which deals with close binary stars. We have only to instance the recent discovery, by Prof. W. W. Campbell, of the Lick Observatory, that at least one star in every five or six is a spectroscopic binary (*Astrophysical Journal*, vol. xiii. p. 89), as an indication of the vastness of the field.

If Prof. Campbell's estimate of the number of binary systems be correct, then there ought, on the consideration that such systems may revolve in any plane, to be at least 800 Algol variables brighter than the ninth magnitude. At present only twenty-two such systems are known to astronomers.

Then, again, the certainty that in variable stars of the Algol type—that is, binary stars revolving round one another almost or actually in contact—we have the first stage in the evolution of a stellar system, gives a unique interest to any investigation, whether spectroscopic or photometric, which has as its purpose the delineation of the conditions of magnitude and movement of such systems.

Of the many problems intimately related to a determination of the elements of orbital movement of any close binary system, two are, I think, of peculiar interest, as bearing directly on the evolution of such systems.

(1) When we have ascertained the size and brightness of the component stars of any system, and also the form, position, and magnitude of the orbit in which they revolve, we can directly deduce the mean density of the system. A full investigation of this and allied problems is given by Mérian in *Comptes rendus* (122, 1254).

A nomenclature adopted by the present writer, in the *Astrophysical Journal* (vol. x. p. 308), meets, I think, more directly the simpler conditions of the problem of the density of a close binary star.

Putting t = time, in days, of revolution ;
 r = semi-axis major of the orbit of the system ;
 p = ratio of the radius of companion (1) to semi-axis major ;
 q = ratio of the radius of companion (2) ;
 m_1 = mass of companion (1) ;
 m_2 = mass of companion (2) ;
 Δ_1 = density of companion (1) ;
 Δ_2 = density of companion (2) ;

(the sun's radius, mass and density are taken as unity) then the simple relation

$$\Delta_1 = \frac{0.0135}{p^3 t^2} \cdot \frac{m_1}{m_1 + m_2}, \quad \dots \quad (1)$$

$$\Delta_2 = \frac{0.0135}{q^3 t^2} \cdot \frac{m_2}{m_1 + m_2}, \quad \dots \quad (2)$$

will determine the values of Δ_1 and Δ_2 when the relative masses of the two component stars are known.

If $p = q$,
 then $\Delta_1 + \Delta_2 = \frac{0.0135}{p^3 t^2} \dots \dots \dots (3)$

It will be at once evident that, since

$$\frac{m_1}{m_1 + m_2} \quad \text{and} \quad \frac{m_2}{m_1 + m_2}$$

must always be less than unity,

$$\Delta_1 < \frac{0.0135}{p^3 t^2};$$

$$\Delta_2 < \frac{0.0135}{q^3 t^2}.$$

These two relations express the limit in one direction of the density of any binary system when the size of the component stars, and the period of variation, has been ascertained from an examination of the light-curve of the variable. In the *Astrophysical Journal* (vol. x. p. 315), Prof. H. N. Russell, of the Princeton University, from considerations similar to the foregoing, deals with the light-variation of seventeen out of the twenty-two Algol variables, deducing from their variation their densities.

He finds the mean density of the seventeen stars considered to be

$$0.19,$$

the density of water being unity.

In the same *Journal* (vol. x. p. 314), the writer discussed the light-changes of four southern Algol variables which had been under observation for some years at Lovedale, South Africa.

The mean density of these four stars was found to be 0.13 that of the sun. If the sun's density be taken as 1.44 times the density of water, then this result would yield as the mean density of the stars considered,

$$0.187.$$

Since this article was written, two new southern Algol variables have been discovered—one at the Cape Royal Observatory and the other at Lovedale. Further, a new photometric equatorial, specially constructed by Messrs. Cooke for variable star work, has made it possible to secure observations, at Lovedale, of all the eight southern Algol variables of considerable accuracy.

A reduction of these observations has just been completed, and an examination of the results gives, as the mean density of all the southern Algol variables at present known, viz. eight, the value

$$0.176.$$

Of the three investigations just given in brief, the first two were independently conceived, carried out, and completed. Yet the results are practically accordant.

There is just the barest possibility that this agreement may be fortuitous; such a remote possibility exists in all investigations.

It is much more probable, however, that the agreement between the results indicates the truth of the conclusion. And this conclusion is that the average density of close binary stars—that is, of bodies just forming, by the compulsion of their inherent forces, into a dual existence—is one-sixth that of water or one-eighth that of the sun.

It is not the purport of the present paper to follow the investigation to its legitimate termination—that is, to discover in what agreement is the result just obtained with the theoretical conditions of density consonant with a rotating ellipsoid on the limit of bipartition. A broad general agreement, however, is evident even on an elementary judgment, for if the result had been that the average density of close binary systems, or of the actual density of any one system, was, say, much greater than that of the earth, then it would be difficult to understand how separation could take place under these conditions. On the other hand, no violence is done to our appreciation of what is reasonable when we find that all close binary systems have a density much less than water; in some single cases, indeed, we meet with densities approaching that of a gaseous nebula. Such a condition of tenuity is evidently favourable to disruption.

Any investigation of the light-changes of an Algol variable, having extreme accuracy in view, must of necessity consider the form of the stars alternately eclipsing one another.

It is evident that the rate of decrease or increase of eclipse will be more rapid the more ellipsoidal in figure the component stars are.

In the case of two spheres eclipsing one another, the amount of obscuration, or the total amount of light emitted by the

system, at any period of the eclipse, can be ascertained from the simplest geometrical considerations. In the case of two spheroids, the computation is not so simple.

Still a relation does exist between the amount of distortion due to the mutual attractions of two adjacent bodies, and the rate of obscuration in any eclipse, and this relation is capable of discernment and computation. The difficulty, however, does not lie in the computation: it lies in our inability to determine observations refined enough to respond to a demand so exacting as that which necessitates observations correct to within two-hundredths of a magnitude.

That this degree of accuracy in photometric measurement has been attained to by more than one observer brings the problem of the determination of the figure of a rotating binary system within a reasonable expectation of solution.

Of the twenty-two Algol variables at present known, five are binary systems the component stars of which revolve in contact. It is, therefore, evident that any investigation having as its purpose the figure of the component members of a close binary system should deal first with these five stars.

Particulars of these stars are as follows:—

Chandler No.	Designation.	R.A. 1900.	Decl. 1900.	Period.	Max.	Min.
		h. m. s.	° ' "	d. h. m. s.	m.	m. m.
2852	V Puppis	7 55 22	-48 58' 4"	1 10 54 27	4' 1	4' 7"-4' 9"
3055	X Carinae	8 29 7	-58 53' 2"	1 1 59 0	7' 9	8' 6"-8' 7"
5099	RR Centauri	14 9 55	-57 23' 3"	0 14 32 7	7' 4	7' 8"-7' 85"
6758	β Lyræ	18 46 23	+33 14' 8"	12 21 46 58	3' 4	3' 9"-4' 5"
8598	U Pegasi	23 52 53	+15 23' 9"	0 8 59 41	9' 3	9' 8"-9' 9"

It may be objected that all along it has been assumed that Algol variables are binary systems. What evidence is there that this is so?

In the only cases where independent confirmation is possible—that is, in cases where the stars are bright enough to be dealt with spectroscopically—this confirmation is forthcoming.

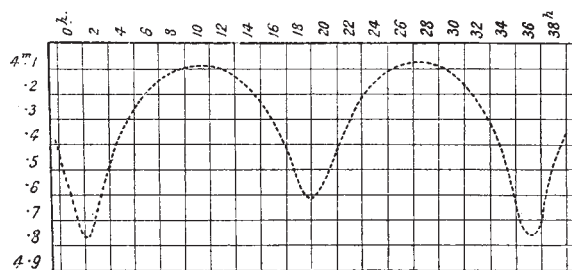


FIG. 1.—Light-curve of V Puppis, from observations made at Lovedale South Africa.

With regard to the foregoing five stars, the spectroscope reveals V Puppis and β Lyræ to be binary systems. The other stars are beyond the reach of spectroscopic examination, at least with its present limitations.

Apart from this, however, revolution and consequent eclipse is the only complete explanation of Algol variation.

In Fig. 1 is given the light-curve of V Puppis, the first star in the list, and this light-curve may be taken as typical of those of the other four stars. Indeed, the light-curve of U Pegasi (*Harvard Circular*, No. 23) is practically identical with that of V Puppis.

The figure of the β Lyræ system has been considered most fully and conclusively by Mr. Myers in the *Astrophysical Journal* (vol. vii. p. 1); one of his definite results being that each star forming the system is not a sphere but an ellipsoid of revolution. The amount of flattening is found to be 0.2 in both stars.

Mr. Myers also deals with the variation of U Pegasi in the same manner (*Astrophysical Journal*, vol. viii. p. 163), and finds that there is distinct evidence, in the form of the light-curve of this star, of an ellipsoidal figure in both components.

In the *Astrophysical Journal* (vol. xiii. p. 177), the writer considered the variation of V Puppis, the first of the five stars. Again it was found that while, to no insufficient extent, the view

that the light-changes were produced by the eclipse of two spheres would meet the facts of variation, an assumption that both components were ellipsoidal in figure would satisfy the observations more fully.

Since the foregoing article was published, an examination of all the observations of X Carinae and RR Centauri made at Lovedale has been completed. It is found that the twin stars of X Carinae have parted company. They are no longer in actual contact, although a distance of only one-tenth of their diameters separates them. The observations of this star also do not indicate an unmistakable distortion of either component.

In the case of RR Centauri we have a twin system similar to that of V Puppis, with this difference, that the form of the light-curve indicates beyond doubt a considerable ellipsoidal form of both stars. Indeed, a dumb-bell figure of equilibrium similar to that indicated in Prof. Darwin's treatise on "Figures of Equilibrium of Rotating Masses of Fluid" (p. 429) would produce variation of the same character as that of RR Centauri.

Of the interest which attaches to all investigations, whether by telescope or spectroscope, concerning these remarkable binary systems, there can be no manner of doubt. For we are dealing with the origin of stellar systems.

Hitherto, in theory only have we had cognisance of some great gaseous orb aggregating itself into two elongated spheroids, dividing after the lapse of long ages into two separate and distinct bodies.

By the action and interaction of their tidal forces, the gap between the component stars grows wider and wider: the system ceases to be a close binary star fulfilling its period in days; it takes months to complete its circuit.

And still the apocentric revolution goes on, until, at last, the star becomes a visual binary, one component separated from its fellow by the width of the whole solar system.

From V Puppis, on the one hand, a dumb-bell system speeding round in thirty-five hours, to the twin stars of Castor, completing their great round in one thousand years, we have a regular chain of sequences in distance.

The links of this chain are made evident by observation as well as by theory. It is not unreasonable, therefore, that the present trend of astrophysical research should be in the direction of discovering more fully and certainly the different stages of evolution and development in the architecture of the heavens.

ALEX. W. ROBERTS.

Lovedale, South Africa, August 9.

A Plea for a Prehistoric Survey of Southern India.

ACCORDING to Mr. R. Bruce Foote, and no one is more competent to speak than he, the urgency for the establishment of a genuine prehistoric survey in Southern India is very great, if the study of this most fascinating branch of archæology is to be encouraged and the wanton destruction of prehistoric monuments checked. Such survey, if honestly carried out, would go far to procure much larger data than yet exist as to the distribution over the southernmost districts of the peninsula of the Palæolithic people whose remains in the shape of chipped stone implements have been found in so many localities in the Carnatic and Deccan plateau, embedded in Pleistocene deposits. Such data might help materially also to bridge over the great hiatus in time which now appears to exist between the era of those very rude people and that of the Neolithic tribes which followed them in the same country.

Further research in the southern districts especially might result in the finding of evidence as to the quarter from which the Dravidian tribes entered the Peninsula—a question of very high ethnological interest.

Another very important ethnological question might possibly be also answered by such investigations, namely, were the first Dravidian immigrants that settled in Southern India in a Neolithic stage of culture, or must the polished-stone people be considered as pre-Dravidian? If the question be answered in the latter way, a fresh immigration must be postulated, by which the true Dravidians reached their present country. If the answer affirms the former proposition, the idea of a further immigration may be dispensed with, for the early iron people appear to be the direct descendants of the Neolithic tribes and the ancestors of the present inhabitants.

Every year numbers of prehistoric burial places are destroyed by the rapacity of the "Waddars," the wandering tribe of tank diggers, who are allowed to annex the fine slabs composing the